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SUMMARY

Girdling was tested alone and in combination with stem injections of gibberellin $A_{4/7}$ ($GA_{4/7}$) on 9-year-old rooted cuttings of Sitka spruce in the Lost Lake seed orchard near Victoria. As is characteristic for this orchard, the untreated trees produced few seed cones and no pollen cones. Girdling did not elicit a flowering response when applied alone, but in combination with $GA_{4/7}$ the trees produced an abundance of both seed and pollen cones. For Sitka spruce, as for other conifers, $GA_{4/7}$ stem injection is a practical and highly effective treatment for promoting flowering in seed orchards.

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INTRODUCTION

Sitka spruce (*Picea sitchensis* Bong. Carr.) is a minor but potentially important tree improvement species in British Columbia. Five cooperative and private seed orchards have been established since 1971 (Hanson 1985), and it appears that most of these will be reasonably productive. Western Forest Product's private 9-year-old Sitka spruce orchard No. 157 at Lost Lake is an exception, however. Located adjacent to a stand of older Douglas-fir, it is subjected to partial shading and cooler temperatures that may be responsible for the poor flowering to date (R. Collins, Mgr. Lost Lake Seed Orchard, pers. comm.).

Flowering in many conifers is enhanced by exogenous applications of the plant growth regulator mixture gibberellin $A_{4/7}$ ($GA_{4/7}$), and its efficacy is frequently enhanced by girdling and other cultural treatments (Pharis *et al.* 1987). An improved method of $GA_{4/7}$ application by pulsed stem injections was recently developed that, in combination with stem girdles, appeared to be not only effective but also practical for treatment of Sitka spruce seed trees (Philipson 1985; Longman *et al.* 1986). The present study was undertaken to evaluate the effectiveness of $GA_{4/7}$ plus girdling, versus girdling alone, for promoting flowering in a poorly producing Sitka spruce seed orchard.

MATERIALS AND METHODS

In spring of 1988, one ramet from each of 30 clones in Western Forest Product's seed orchard No. 157 was randomly assigned to receive: (1) no treatment, (2) stem girdles only, and (3) girdles plus $GA_{4/7}$ stem injections. Stem diameters of the 8- to 9-year-old rooted cuttings of mature parent trees ranged from 6 to 9 cm at the base of the live crown (30-60 cm above ground).

Double, over-lapping saw girdles (Wheeler *et al.* 1985) were applied in spring at the mid- to late stage of vegetative bud swell. The two girdles were separated by a distance of 10 cm, the upper girdle being approximately 20 cm below the lowermost live branch.

Trees received 100 mg $GA_{4/7}$[1] divided between two injections, at vegetative bud burst in spring and 2 weeks later. On each date, 25 mg $GA_{4/7}$ in 0.5 mL 95% ethanol was injected into each of two holes. These were drilled 25 mm deep at a slight downward angle with a 6-mm (1/4-inch) bit on opposing sides of the main stem 10-15 cm below the lowermost live branch and 5 cm above the upper girdle. The second set of injection holes was 5 cm above and offset 90° from the first. Immediately after injection, the holes were plugged with a short length of 1/4-inch wood dowel, and they along with the girdles were sprayed with Tree Tanglefoot (The Tanglefoot Co., Grand Rapids, Mich., USA) as protection against *Diorectria* spp. and other boring insects.

Seed and pollen cones were counted shortly after emergence in spring 1989. Analysis of variance was performed on the cone-count data, using planned contrasts to compare different treatments.

RESULTS

Differences among treatments were highly significant in numbers of seed and pollen cones initiated per tree (Table 1, Figure 1). Differences among clones were not significant; the clone by treatment interaction was not testable since treatments were not replicated on ramets within clones.

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[1] Purchased through patent agreement with ICI Ltd. (UK) from Dr. R.P. Pharis, Department of Biology, University of Calgary, Alberta, T2N 1N4.

TABLE 1. Summary of analysis of variance on cones per tree[a]

Source of variation	DF	Seed cones		Pollen cones	
		SS	P	SS	P
Clones (C)	29	1 520 689	0.223	214 590	0.670
Treatments (T)	2	2 732 058	<0.001	79 667	0.012
Contrasts					
Untr. v gird	1	960	0.880	8 664	0.321
Untr. v G+GA	1	2 004 219	<0.001	76 898	0.004
Gird. v G+GA	1	2 092 907	<0.001	33 939	0.052
CxT	58	6 690 256		501 206	
Total	**89**	**6 690 256**		**795 484**	

[a] SS = sums of squares; P = the probability of type I error for listed effect.

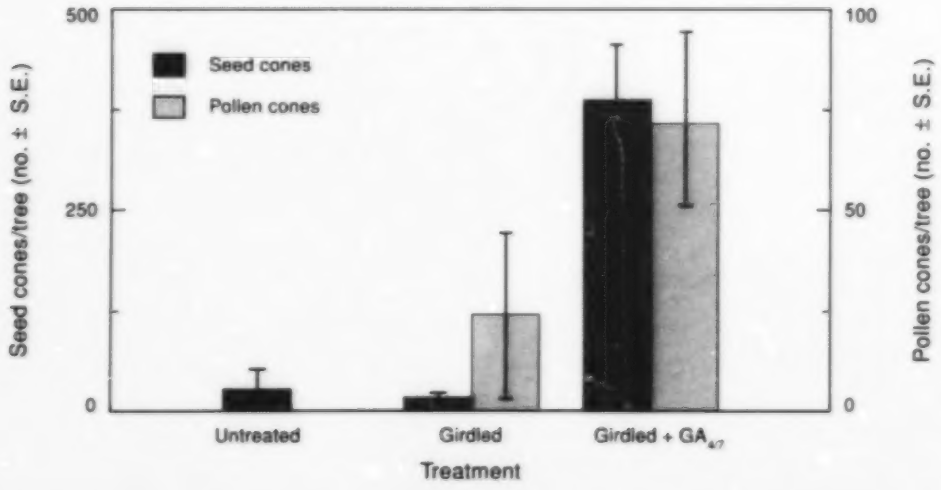

FIGURE 1. Flowering response by 9-year-old Sitka spruce rooted cutting to girdling and stem injections of $GA_{4/7}$.

Fifty-six percent of clones produced seed cones without treatment, and the mean number of cones per tree was 26. Girdling alone affected neither the percentage of clones flowering (60%), nor the mean number of seed cones per tree (18). In response to girdling + $GA_{4/7}$, however, 87% of clones flowered, and the mean production of seed cones was increased 14 fold (to 392 per tree) relative to no treatment.

The untreated trees produced no pollen cones. Girdled trees averaged 24 pollen cones each, with 17% of clones contributing to production. This effect of girdling alone was not significant and was small relative to that from girdling + $GA_{4/7}$. Here, 40% of the clones flowered, and the mean number of pollen cones per tree was 74.

DISCUSSION

These results confirm the effectiveness of $GA_{4/7}$ stem injections in promoting flowering of Sitka spruce (Philipson 1985; Longman *et al.* 1986). The practicality of the stem injection technique for $GA_{4/7}$ treatment of seed-orchard trees has since been demonstrated also for other species of spruce (Bonnet-Masimbert 1989; Oldfield 1989; Ross 1991b), as well as Douglas-fir (Ross and Bower 1989, 1991), western hemlock (Parkinson 1989), Jack pine (Oldfield 1989), and western larch (Ross 1991a). Following the protocol of Philipson (1985), the treatment consisted of two injections of $GA_{4/7}$, 2 weeks apart. Results for Douglas-fir (Ross and Bower 1989) and Engelmann-white spruce (Ross 1991b) suggest that a single injection shortly after vegetative bud burst should be just as effective and significantly more cost efficient.

The $GA_{4/7}$ was applied to girdled trees, and in other studies on Sitka spruce (Philipson 1985; Longman *et al.* 1986) and Douglas-fir (Ross and Bower 1989) girdling significantly enhanced the flowering response to $GA_{4/7}$. However, it is unlikely that this occurred in the present work where girdling was ineffective by itself as a cone enhancement treatment. Other studies confirm that girdling is not always a useful adjunct to $GA_{4/7}$ stem injections (Oldfield 1989; Ross 1991a,b). It appears that girdling will be most effective, if at all, on poor-flowering clones (Ross 1991b), in years or on sites where conditions for flowering are marginal (Longman *et al.* 1986; Ross 1991b), or where $GA_{4/7}$ is applied at a sub-optimal dose (Philipson 1985).

Even then some workers are reluctant to recommend girdling as an operational treatment in seed orchards because of the possibility of stem breakage and other adverse effects of wounding (Longman *et al.* 1986; Bonnet-Masimbert 1989; Oldfield 1989). The $GA_{4/7}$ can be slightly phytotoxic, but this is normally limited to some chlorosis and premature shedding of older, less productive needles (Ross 1983). Although not evident in the present study, this effect may be exacerbated by the additional stress of girdling, with possibly severe carry-over effects on vegetative development (Bonnet-Masimbert1989) and flowering in subsequent years (Ross and Bower 1989, 1991; Ross 1991b).

RECOMMENDATIONS

Properly applied, $GA_{4/7}$ is a safe and cost-effective treatment for promoting flowering in seed orchards of Sitka spruce and other conifers (Philipson 1985; Ross and Bower 1989, 1991). Although not monitored in the present study, the $GA_{4/7}$ treatment has been found not to affect cone or seed development significantly (Longman *et al.* 1986; Ross and Bower 1991). Although there can be no guarantee that the treatment will work on all clones in every orchard every year, the following protocol should ensure maximum success under most circumstances.

Tree size:

There is apparently no lower or upper limit to the size of trees that will respond to $GA_{4/7}$ treatment. However, trees smaller than 6 cm DBH will probably benefit from additional vegetative development before starting induction treatment, and those larger than 24 cm should be sufficiently mature to flower on their own.

$GA_{4/7}$ dosage:

It is necessary to adjust the $GA_{4/7}$ dosage to tree size. The recommended dose is 60 mg $GA_{4/7}$ injected in 0.5 mL alcohol (ethanol, isopropyl or methanol) per hole, with one hole drilled as previously described for each 14 cm of stem circumference at the point of injection. Injections are most conveniently made at breast height, unless the trees are very small, in which case injections should be made at the base of the live crown. This will ensure maximum promotion of pollen cones, which tend to be restricted to the lowermost crown.

Timing:

Although trees in this study received two injections of $GA_{4/7}$, there is sufficient evidence from other species to suggest that a single injection will be nearly as effective and far less costly (Ross and Bower 1989; Ross 1991b). The $GA_{4/7}$ should be applied within 2 weeks of vegetative bud burst in spring, although treatment up to the time that shoot elongation is about 90% complete may still be effective (Marquard and Hanover 1984; Philipson 1985).

Retreatment frequency:

As previous experience with Douglas-fir (Ross and Bower 1990) and interior spruce (Ross 1991b) suggests, I recommend a 3-year interval between treatments. However, if trees are healthy and vigorous in appearance following maturation of the induced cone crop, they can presumably be safely retreated every other year.

Adjunct treatments:

For reasons already discussed, girdling is not recommended as an adjunct to $GA_{4/7}$ treatment. However, the combined treatment may be necessary for those orchards and clones that do not respond to $GA_{4/7}$ alone. Under these conditions, high dosages of nitrogen fertilizer (i.e., 200 kg $N.ha^{-1}$ as ammonium-nitrate) before flushing in spring may be substituted for girdling. Otherwise, trees should be fertilized only as required to remedy nutrient deficiencies as identified by foliar analysis.

If the orchard has irrigation capability, watering should be withheld during the period that shoots are actively elongating. Thereafter, the trees should be well watered as they would normally be for vegetative development. Drought during this later period is not only inhibitory to flowering in spruce (Ross 1985), but it may also exacerbate the potentially phytotoxic effects of $GA_{4/7}$ (Ross and Bower 1989, 1991).

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